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# Vibrational Analysis in Condition Monitoring and faults Diagnosis of Rotating Shaft - Over View

Nagaraju Tenali[1], Dr P.Ravindra Babu[2], K. Ch. Kishor Kumar[3]

[1] Assistant Professor, Mechanical Engineering Department, Gudlavalleru Engineering College, Sheshadri Rao Knowledge Village, Gudlavalleru- 521356, Andhra Pradesh, India

[2]Professor Mechanical Engineering Department, Gudlavalleru Engineering College, Sheshadri Rao Knowledge Village, Gudlavalleru- 521356, Andhra Pradesh, India

[3]Associate Professor Mechanical Engineering Department, Gudlavalleru Engineering College, Sheshadri Rao Knowledge Village, Gudlavalleru- 521356, Andhra Pradesh, India

***Abstract—*** *Rotating shaft is a vital element in power stations like Gas power stations, steam power station and Tidal power stations. These shaft failure or break down lead to the consequences, ranges from annoyance to the financial disaster or human damage. Hence predictive maintenance which includes early detection, identification and correction of machinery problems is paramount to anyone involved in the maintenance of industrial machinery to insure continued, safe and productive operation. Condition monitoring of machines is become necessary to run the machines efficiently. Vibrations are caused due to unbalance in the rotating components, dry friction between the two mating surfaces, misalignments, imperfect of coupling or bearings, and cracks in the shafts or blades. In predictive maintenance, vibration monitoring and analysis is essential. Health of any rotating shaft can be identified by its signature includes number of peaks. The peaks in the spectrum or signature give the information regarding the type of fault. In this paper gives a overview on vibrations analysis and faults diagnosis in various rotating machine parts and also this paper attempts to epitomize the recent research and developments in rotating element vibration analysis techniques.*

***Keyworks— Vibrations Analysis, Condition monitoring, Fault Diagnosis.***

## I. INTRODUCTION

Every machine consists of rotating parts like bearings, Gears and rotating shafts etc., Failure of these components may lead to cost of unplanned down time, loss of life or machinery. This can be minimized by identification of the failure before it occurrence which is called predictive maintenance. Condition monitoring is one of best technique among various predictive maintenance techniques. Condition monitoring is the process of continuously monitoring the working health of machinery.

### 1.1 Condition Monitoring Techniques

The following are the major seven techniques of condition monitoring and are commonly used.

They are:

1. Visual monitoring
2. Contaminant or debris monitoring
3. Performance and behavior monitoring
4. Temperature monitoring or IR Thermography
5. Sound monitoring.
6. Shock pulse monitoring.
7. Vibration monitoring using spectrum analyzer. [1]

### 1.2 Detection of cracks in rotor shaft

High vibration amplitude in rotor system may due to fault in any one of the part of rotating machine or crack in the rotating shaft. Operating rotating machinery with a cracked rotor is very dangerous because the rotor crack grows with time and rotor may fail due to fatigue, causing a catastrophic accident. It is mandatory to check the occurrence of a rotor crack in time to time inspections during general maintenance of the system using the ultrasonic testing method or the dye testing method. However, these methods have own disadvantages such as more cost and difficulty in early detection method. Vibration diagnosis of a rotor crack by paying attention to the changes of vibration characteristics has been investigated [2, 3]. On his survey Gasch [4] reported the dynamic behavior of the de Laval rotor with a transverse crack. Grabowski [5] investigated a theoretical model of the crack mechanism and performed numerical simulation. Dimarogonas [6] used the de Laval rotor and compared with experiments. Inagaki [7], Mayes [8], and Nelson [9]

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investigated a general rotor system with a transverse crack using methods such as the transfer matrix method, and finite element method. Some of them [7, 10] performed experiments using a test rotor and compared with theoretical results. The propeller-bearing-shaft system has been holistically modeled using FE procedure with the actual in-situ profiles for the propeller, bearings, supports and torque loading aluminum arm. Also vibration analysis for experimental results has been successfully correlated with the finite element results. These results show that it is possible to detect the crack presence beyond the crack depth ratio of 20% [11]. A harmonic excitation force is applied to the cracked rotor and its excitation frequency is swept, and the nonlinear resonances due to crack are investigated. The occurrence of various types of nonlinear resonances due to crack are clarified, and types of these resonances, their resonance points, and dominant frequency component of these resonances are clarified numerically and experimentally [12].

### 1.3 Detection of rotor shat unbalance

Another important reason for high vibration is due to unbalance of masses, an unbalanced rotor always produces high vibrations and generates excessive force on the bearing area and reduces the life of the rotating machine. The vibration Produced due to unbalance may damage critical parts of the machine, such as bearings, seals, gears and couplings etc. In actual practice, rotors can never be perfectly balanced because of manufacturing errors like non-uniform density of material, tolerances in manufacturing, loss of material during operation, porous casting[13]. Mechanical malfunctions such as, rotor unbalance and shaft misalignment are the most common causes of vibration in rotating machineries. Excessive unbalance can lead to fatigue of machine components and can cause wear in bearings or internal rubs that can damage seals and degrade machine performance. The unbalance part of the rotor rotates at the same speed as the rotor and therefore the force caused by the unbalance is synchronous [14].

### 1.4 Detection of bearing defects

Rotating shaft system may be shutdown due to defects in the bearings. Vibration based condition monitoring is the process, which monitors the engine parameters periodically in order to ensure safety of the machine and hence predicts the faults in the system before occurrence of a catastrophic failure [15]. Vibration Monitoring is carried out with the help of accelerometers, which senses the vibration in the bearing and provides the required data for analysis. This can be carried out by three methods, namely, Time domain analysis, Frequency domain analysis, and Time frequency analysis. All the three techniques have been described in detail [16]. Vibration signals collected from bearings reviles much information about machine health conditions. Therefore, the vibration-based methods have received greater intensive study during the past decades. We can obtain vital characteristic information from the vibration signals through the use of signal processing techniques [17]. Bearing may fail by either of the following reasons - bearing subjected to normal loading will fail due to material fatigue such as pitting, spalling or after a certain running time. Fatigue damage begins with the formation of minute cracks below the bearing surface [18, 19]. As loading continues, the cracks progress to the surface where they cause material to break. The surface damage severely disturbs the motion of the rolling elements which leads to the generation of short time impacts repeated at rolling element defect frequency [20, 21, 22]. Wear is common cause of bearing failure, caused mainly by dirt & foreign particles entering the bearing through inadequate lubrication. Severe wear changes the raceway profile & alters the rolling element profile, increasing the bearing clearance. Increase in rolling friction leads to high levels of slip & skidding, results in complete breakdown [18]. Corrosion damage occurs when water, acids or other contaminants in the oil enter the bearing arrangement. This can be caused by damaged seals, acidic lubricants or condensation. As the rust particles interfere with the lubrication rust on the running surfaces produces uneven & noisy operation. Incorrect design can involve poor choice of bearing type or size for the required operation. Incorrect bearing selection can result in low load carrying capability the end result will be reduced fatigue life. [23].

## II. VIBRATION ANALYSIS TECHNIQUES

There is several vibration analysis techniques used to analyze the rotor shaft system vibration. In this paper the vibration analysis technique categorized the following way: Time domain, Frequency domain, Time Frequency Analysis, Cepstrum Analysis

### 2.1 Time domain analysis

Time domain analysis is the process in which statistical features are computed from the vibration data. By comparing the statistical features, particular faults can be identified. The statistical features that are used for time domain analysis in this paper are mean (M), variance (σV),

Root Mean Square (RMS), Kurtosis (K), Skewness (S). These statistical features are described in this section.

**Mean (M)**

Mean is the average of the total number of samples in the vibration signal x (n) as:

$$\mathrm{M} = \frac{1}{N} \sum_{n=0}^{N-1} x(n)$$

Where, N is the length of the vibration signal and X (n) is the raw vibration signal.

**Variance (σV)**

Variance is the square of standard deviation. Hence, it is also useful in differentiating between the normal and faulty rotating elements. It is represented as:

$$\sigma_{\mathrm{V}} = \frac{1}{N} \sum_{n=0}^{N-1} (x(n) - \mu)^2$$

**Root Mean Square (RMS)**

The Root Mean Square (RMS) value indicates the power content in the vibration signal. RMS is the effective value of the vibration signal. It can also be defined as the standard deviation of the signal. It is a feature, suited for steady state signals. As the rotor shaft elements life approaches the end RMS level increases considerably [24]. It provides excellent results in following the noise level throughout the signal and is the normalized second statistical moment of the signal [25]. It is represented as:

$$RMS = \sqrt{\frac{1}{N} \sum_{n=0}^{N-1} \left(x(n) - \mu\right)^2}$$

Skewness (S)

Skewness is the normalized third statistical moment of the signal. It indicates the relative energy over and under the mean level [26]. It is represented as:

$$S = \frac{\frac{1}{N} \sum_{n=0}^{N-1} \left(x(n) - \mu\right)^3}{RMS^3}$$

**Kurtosis (K)**

Kurtosis is the normalized fourth statistical moment of the signal. It indicates the impulsive nature of the signal. Since the signal is raised to the fourth power, it effectively amplifies the isolated peaks in the signal [27]. Kurtosis value is a negotiation between the tactless lower moments and extra-sensitive higher moments [26]. Kurtosis increases rapidly at the initial stage of a fault itself which is very helpful in finding the faults [24]. For continuous time signals, kurtosis is defined as

$$K = \frac{\frac{1}{N} \sum_{n=0}^{N-1} \left(x(n) - \mu\right)^4}{RMS^4}$$

**2.2 Frequency Domain Techniques**

Frequency domain, or spectral analysis, is the most popular technique for the diagnosis of faults of various rotating members. Frequency-domain techniques converts' time-domain vibration signals into discrete frequency components using a fast Fourier transform (FFT). Simply stated, FFT mathematically converts time-domain vibration signals trace into a series of discrete frequency components. The Fast Fourier Transform (FFT) is an algorithm for calculation of the Desecrate Fourier Transform first published in 1965 by J.W.Cooley and J.W.Tuckey [28].In a frequency spectrum plot, the X-axis is frequency and the Y-axis is the amplitude of displacement, velocity, or acceleration. The main advantage of frequency-domain analysis over time-domain analysis is that it has ability to easily detect the certain frequency components of interest. James Taylor [29] well explained the sequence of appearing and disappearing of peaks in the spectrum. The detailed knowledge of bearing characteristics frequencies (see section-III) required to indentify the location of defect in rolling element bearing. Power spectrum is used to identify the location of rolling element defects by relating the characteristic defect frequencies to the major frequency components which can be found in the spectrum. Power cepstrum is important bearing fault detection technique and it is defined as the inverse Fourier transform of the logarithmic power spectrum. A modified cepstrum analysis was proposed by Merwe and Hoffman [30].

**2.3 Time -Frequency Domain Techniques**

Time-frequency domain techniques have capability to handle both, stationary and non- stationary vibration signals. This is the main advantage over frequency domain techniques. Time–frequency analysis can show the signal frequency components, reveals their time variant features. A number of time-frequency analysis methods, such as the Short-Time Fourier Transform (STFT), Wigner-Ville Distribution (WVD), and Wavelet Transform (WT), have been introduced. STFT method is used to diagnosis of rolling element bearing faults [31]. The basic idea of the

STFT is to divide the initial signal into segments with short-time window and then apply the Fourier transform to each time segment to ascertain the frequencies that existed in that segment. The advantage of wavelet transform (WT) over the STFT is that it can achieve high frequency resolutions with sharper time resolutions. An enhanced Kurtogram method used to diagnosis of rolling element bearing faults by Wang et al. [32].

## III. CONCLUSION

In this paper an attempt made to epitomize the recent development in condition monitoring using vibration analysis techniques for diagnosis defect in rotary shaft. This study reveals that the time domain techniques and frequency domain techniques can indicate the faults in the rotor, but time domain technique can't identify the location. Frequency domain techniques have ability to identify the location of fault(s) in rotor.

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